EIC Detector R&D Progress Report

Project ID: eRD3

Project Name: Design and assembly of fast and lightweight barrel and forward tracking prototype systems for an EIC

Period Reported: October 01, 2014 - September 30, 2015 (Status) / October 01, 2015 - September 30, 2015 (Proposal)

Project Leaders:
Professor Bernd Surrow (Temple University) / Dr. Franck Sabatie (Saclay)

Date: June 15, 2015

Applicant Address: Temple Univesity
Department of Physics, SERC
1925 North 12th Street
Philadelphia, PA, 19122

Contact Person: Professor Bernd Surrow

Email: surrow@temple.edu

Phone: 215-204-7644

Introduction

This report concentrates on a dedicated tracking system based on micropattern detectors, which focuses on the design and development of fast and lightweight detectors, ideally suited for a future EIC experiment. The science case and basic detector specifications have been documented in a White paper report [1]. The micropattern tracking detector system consists of:

- Barrel tracking system based on MicroMegas detectors manufactured as six cylindrical shell elements.
- Rear / Forward tracking system based on triple-GEM detectors manufactured as planar segments of three layers in the rear and forward directions.

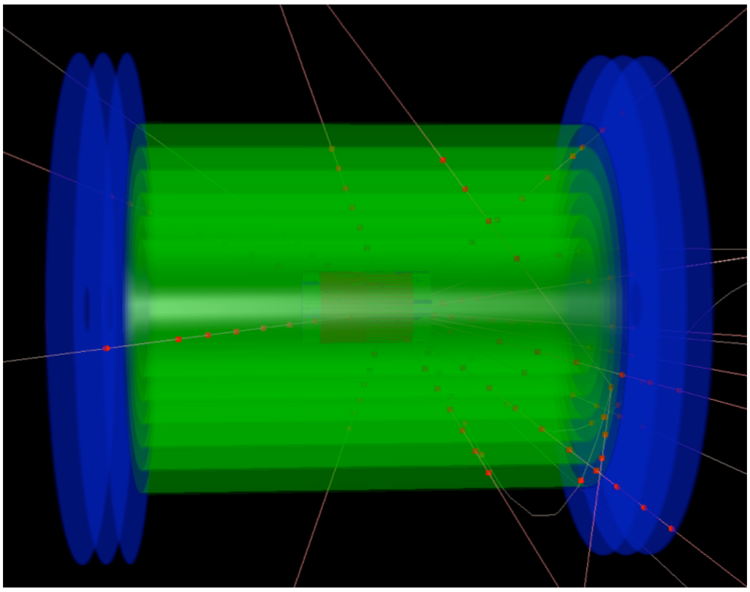

Figure 1: *GEANT simulation of barrel (green) and rear/forward (blue) tracking systems for an EIC detector.*

Figure 1 shows a 3D view of a GEANT simulation for a barrel and rear / forward tracking system which has been initiated by the R&D program documented in this report. The R&D effort focuses on the following areas:

- Design and assembly of large cylindrical MicroMegas detector elements and planar triple-GEM detectors
- Test and characterization of MicroMegas and triple-GEM prototype detectors
- Design and test of a new chip readout system employing the CLAS12 `DREAM' chip development, ideally suited for micropattern detectors
- Utilization of light-weight materials
- Development and commercial fabrication of various critical detector elements, in particular the commercial development of large single-mask GEM foil production
- European/US collaborative effort on EIC detector development (CEA Saclay and Temple University).

This report provides an overview of various R&D activities in the FY15 both in the barrel and rear / forward directions following the last meeting of the EIC R&D committee in January 2015. The allocation of funds of $240k for FY15 as stated in the award letter from August 01, 2014 was finally obtained in February 2015. These resources were needed to complete the R&D program for the planar triple-GEM detectors and in particular the urgent need for a dedicated common chip readout system. As stated in the closeout report following the EIC R&D committee in July 2014, preference should be made to the GEM R&D effort due to budget limitations. We acknowledge this, but would like to point out that the MicroMegas R&D program is the only one of its kind within the whole EIC R&D program. It should be emphasized that our R&D program is a dedicated development of various elements for a future EIC tracking detector system.

Forward Triple-GEM R&D program

Past

What was planned for this period?

Over the time period of 10/14 to 09/15, we had planned to carry out R&D efforts in several areas

1. Relocation and laboratory setup of dedicated micro-pattern development space at Temple University. This includes a dedicated class 1,000 clean room that will be dedicated to optically and electrically testing GEM foils, as well as assembling triple GEM detectors. Additionally we will move to a dedicated lab space which will have a portable class 1,000 clean room and be used for testing and characterizing triple GEM detectors.
2. Optically characterize several CERN 10 cm x 10 cm single-mask GEM foils in order to provide a direct comparison to the 10 cm x 10 cm and 40 cm x 40 cm single-mask GEM foils produced at Tech-Etch. This would allow us to compare Tech-Etch's established production foils directly to CERN's to better access the quality of the GEM foils.
3. The continued development of commercially available large GEM foils from Tech-Etch. Specifically increasing the single-mask GEM foils size to 50 cm x 50 cm, with the ultimate goal being to develop foils on the order of 1 m long.
4. During our initial optical analysis of some initial 50 cm x 50 cm single-mask GEM foils from Tech-Etch, it was realized that in order to accommodate larger GEM foils and optically characterize them in a reasonable amount of time we will need to update our optical scanner setup.
5. Build prototype triple GEM detectors using Tech-Etch single-mask GEM foils of 10 cm x 10 cm and 40 cm x 40 cm. These prototypes will be used to characterize the gain using a ^{55}Fe source. The 10 cm x 10 cm triple GEM detector will use a newly commissioned

CAEN HV system to adjust the potential difference around each GEM foil and study clustering techniques. A new X-ray source was purchased, which will be used with an existing X-Y scanning setup for GEM detectors up to 40cm x 40cm in size.

6. It is planned to build two FGT-type (40 cm x 40 cm Tech-Etch single-mask foils) triple-GEM detectors using Apical spacer grids to attempt to further reduce the material budget. The design has already been discussed in the previous reports.
7. Develop a common large single-mask GEM foil design in accordance with Florida Institute of Technology and University of Virginia for use in an EIC prototype GEM detector.
8. The development of new electronics based on the DREAM chip, which will interface with the prototype GEM and MicroMegas detectors.

What was achieved?

It should be kept in mind that the requested R&D funds which were allocated in the award letter on August 01, 2014 only became available at Temple University in February 2015. In addition, Saclay did not receive any dedicated funding for the Micro-Megas development. However, the group managed to carry the effort forward at some level by taking advantage of overlap with other ongoing efforts.

First EIC Tracking R&D Workshop

The Temple University group hosted the first Tracking R&D Workshop to intensify collaborative efforts of the EIC Tracking R&D program. The WWW-page for the workshop with a link to the agenda is available from here:

https://phys.cst.temple.edu/~surrow/EIC-RD-WORKSHOP/index.html

Laboratory setup and infrastructure at Temple University

Nearly all of the planned R&D has been completed or is currently underway. The relocation and laboratory setup into the new Science Education and Research Center (SERC) has been nearly completed. The College of Science and Technology provided dedicated lab space for the development of micro-pattern detectors focusing in particular on triple-GEM detectors in the current Department of Physics:

- Clean Room (~500 sq.ft.), Class 1,000: Handling of bare GEM foils including leakage current measurements and triple-GEM detector assembly / Microscope inspection of GEM foils
- Detector lab (~1000 sq.ft.): Testing of triple-GEM detectors including cosmic-ray testing, ^{55}Fe-source testing and gas leak testing. A dedicated DAQ system based on the STAR FGT DAQ system is fully operational
- CCD camera lab (~500 sq.ft.) exclusively used for the optical scanning of GEM foils

The maintenance of the clean room is provided by the College of Science and Technology.

The Department of Physics provides a new well-equipped electronics and machine shop. The support from the technical staff was instrumental for the completion of various assembly and testing setups. The electronics and machine shops along with the technical staff are also now available to the Department of Physics at SERC.

Figure 2 shows an overview of the new Science Education and Research Center. Professor Bernd Surrow played a leading role in the layout of the dedicated, large Class 1,000 clean room facility (1,800 sq.ft.) shown in Figure 2 (a). The main focus of the research activities are large micro-pattern detector development and silicon sensor handling, testing, and assembly. In addition to the Class 1,000 clean room facility, Professor Bernd Surrow participated in the layout of a dedicated detector lab (800 sq.ft.) shown in Figure 2 (b). Figure 3 (a) provides an overview of the clean room space dedicated to micropattern detector development at Temple University in the new Department of Physics located at SERC. Figure 3 (b) highlights the electrical GEM testing station, (c) the GEM foil stretching station, and (d) a newly installed optical table (provided by Temple University), a soldering station in the back, and our current CCD GEM scanner setup.

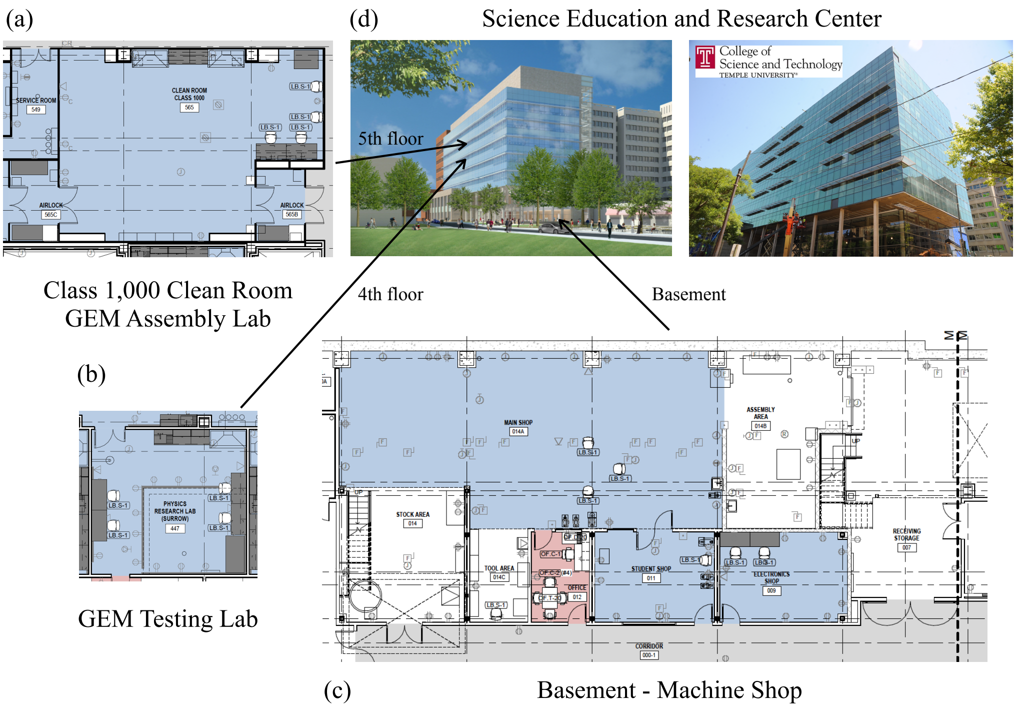

Figure 2: *Overview of the Science Education and Research Center (SERC) (d) with state-of-the-art laboratory infrastructure based on a large Class 1,000 clean room (a) and GEM testing lab (b) along with a large machine shop (c) providing support for the Temple University research programs within the Department of Physics. The photograph of the SERC building (d) was taken on June 16, 2014.*

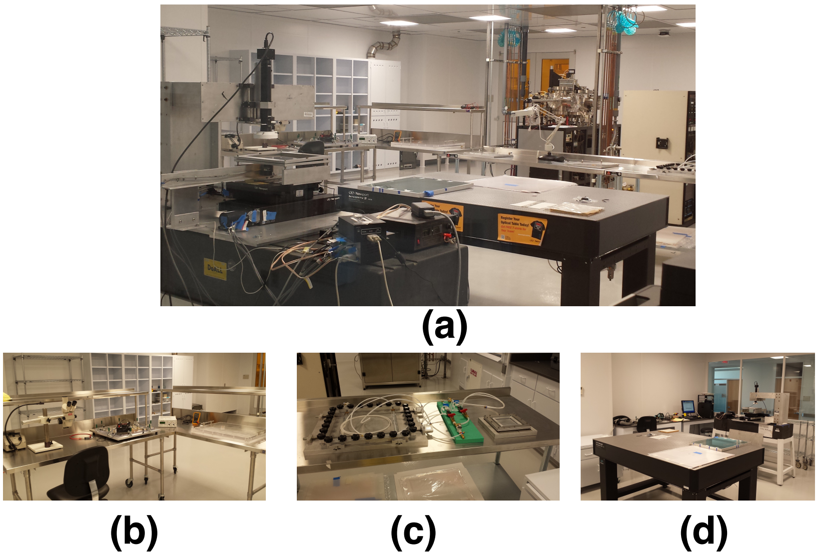

Figure 3*: (a) Overview of the class 1,000 clean room at SERC dedicated to micropattern detector development. (b) Electrical GEM testing setup. (c) GEM foil stretching jigs for 40 cm x 40 cm and 10cm x 10 cm GEM foils. (d) Soldering station, optical table, and current CCD scanner setup.*

<u>Commercialization of single-mask GEM foils</u>

The Nuclear and Particle Physics community require large quantities of large-size GEM foils such as for the upgraded CMS muon system, the ALICE TPC upgrade, and eventually for an EIC detector. The CERN photolithographic workshop has therefore started a collaborative process with Tech-Etch to transfer the CERN technology [2] to Tech-Etch with the goal in mind to provide commercially produced large GEM foils based on single-mask techniques. The management at Tech-Etch signed all technology transfer agreements. The Temple University group agreed with the Tech-Etch management to start the process with the single-mask production of 10 cm x 10 cm GEM foils followed by FGT-type GEM foils (about 40 cm x 40cm) based on existing Gerber files. It was agreed that the Temple University group would test those foils and provide feedback to optimize the single-mask production at the Tech-Etch production plant. The Yale University group agreed to provide in addition ^{55}Fe source measurements of single foils. The Temple University group has been hosting ongoing phone meetings between CERN, Tech-Etch, and other institutions including FIT, UVa, Temple University, and Yale University. Samples of both 10 cm x 10 cm (18 foils) and FGT sized 40 cm x 40 cm (3 foils) single-mask foils have been fully electrically and optically characterized [3].

As a final quality assurance test, 3 CERN 10 cm x 10 cm single-mask GEM foils have been electrically and optically measured using Temple University's electrical testing fixture and CCD scanner, respectively. These measurements were performed in the same manner as those used to measure the Tech-Etch foils, which were described in previous progress reports.

The electrical properties of the CERN foils, which also use APICAL as the polyimide layer (actually Tech-Etch orders their base material directly from CERN), were found to have the same superb performance as seen in the Tech-Etch foils. The typical leakage current seen on all CERN and Tech-Etch foils was ~ 1nA.

The optical analysis of all three CERN single-mask 10 cm x 10 cm GEM foils has been completed. The distributions of the pitch, inner, and outer hole diameters were measured and compared to those found with the 10 cm x 10 cm and 40 cm x 40 cm Tech-Etch GEM foils. The overall geometrical properties of the CERN and Tech-Etch foils agree very well with one another. Figure 4 shows a comparison between the CERN and Tech-Etch foils for the inner hole diameters. Figure 4 (a-c) shows the inner diameter distribution for each of the 3 CERN single-mask 10 cm x 10 cm foils. While (d) shows the Tech-Etch inner diameter means from 6 of their 10 cm x 10 cm GEM foils, and (e) shows mean inner hole diameters for each CCD scan region from each of the 3 Tech-Etch 40 cm x 40 cm foils. From the figures one can see good agreement in the mean inner diameter and spread of the inner hole distributions between the CERN and Tech-Etch single-mask foils. A similar agreement was found in the mean pitch and outer hole distributions. The agreement in the outer hole geometry between CERN and Tech-Etch can be seen in Figure 5. This analysis solidifies Tech-Etch's ability to produce physics production like single-mask GEM foils up to 40 cm x 40 cm in size.

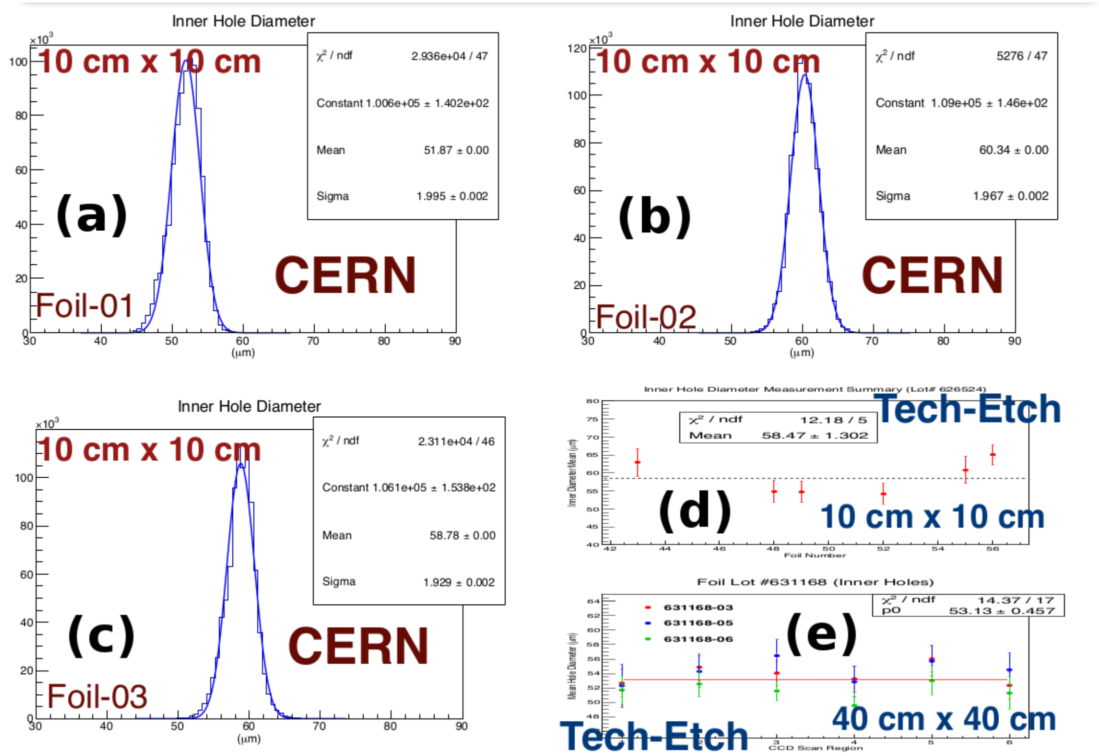

Figure 4: *Comparison of CERN and Tech-Etch inner hole diameters. (a – c): CERN 10 cm x 10 cm single-mask GEM foils, which have an average inner diameter of 56 um and a distribution width of ~ 2um. (d): Tech-Etch 10 cm x 10 cm single-mask GEM foils, which have an average inner diameter of about 58 um, with a distribution spread of about 3 um. (e): Tech-Etch 40 cm x 40 cm single-mask GEM foils, which have a mean inner diameter of around 53 um and a spread of about 2 um.*

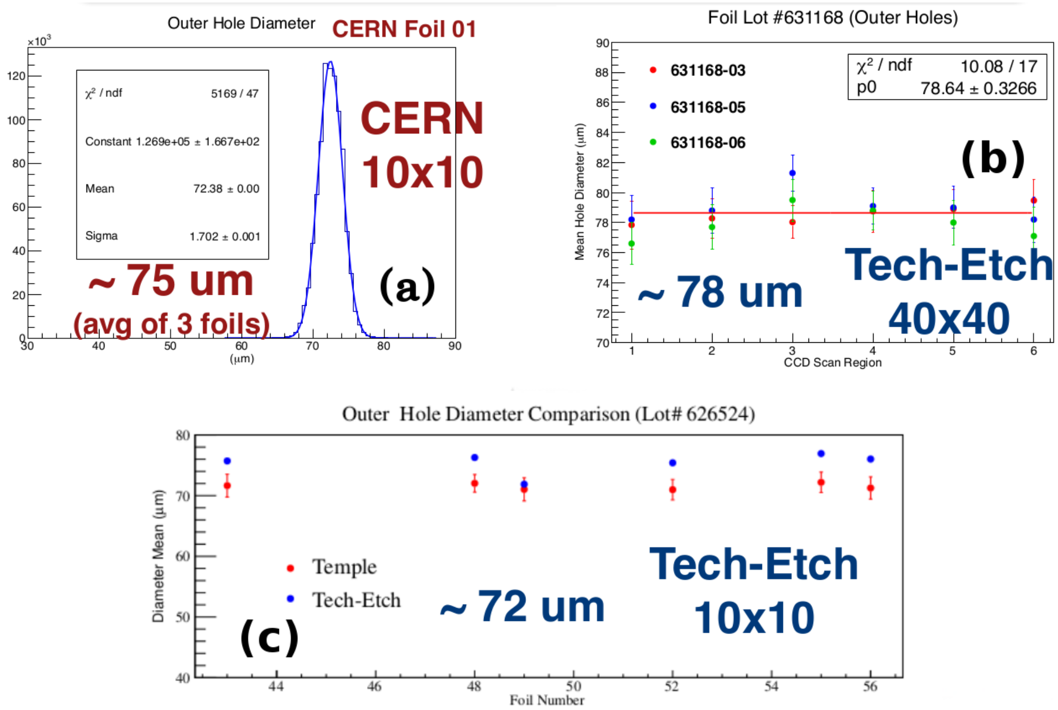

Figure 5: *Comparison of CERN and Tech-Etch outer hole diameters. (a): A representative CERN 10 cm x 10 cm single-mask GEM foil outer hole distribution, which has an average (over 3 foils) outer hole diameter of 75 um and a distribution width of ~ 1.6 um. (b): Tech-Etch 40 cm x 40 cm single-mask GEM foils, which have an average outer hole diameter of about 78 um, with a distribution spread of about 1.4 um. (c): Tech-Etch 10 cm x 10 cm single-mask GEM foils, which have a mean outer hole diameter of around 72 um and a spread of about 1.7 um. The red markers represent measurements done at Temple University by analyzing the entire active area of the foil. The blue markers are independent measurements done a Tech-Etch, which considered only about 9 holes.*

Building on the successful production of their 40 cm x 40 cm GEM foils, Tech-Etch has begun manufacturing 50 cm x 50 cm single-mask GEM foils. These foils represent the largest foils currently possible at Tech-Etch. Larger size foils, such as the common EIC GEM foil prototype, would require an upgrade of Tech-Etch's facilities. Temple University has now received an initial test batch of the 50 cm x 50 cm foils from Tech-Etch, which they knowingly etched larger holes than desired. The pitch and inner hole diameters have been measured for 1 of the 50 cm x 50 cm Tech-Etch foils. The foil was divided into 6 CCD scanning regions, similar to that of the 40 cm x 40 cm foils, due to the size constraint of our current CCD scanner. The pitch of this foil was found to be the same in each of the 6 CCD scan regions, shown in Figure 6, and agrees very well with the values measured in the Tech-Etch 10 cm x 10 cm and 40 cm x 40 cm foils. The inner hole diameters on average were found to be slightly larger than desired, however the deviation from the mean value looks good. A representative inner hole distribution for one of the CCD scan regions can be seen in Figure 7.

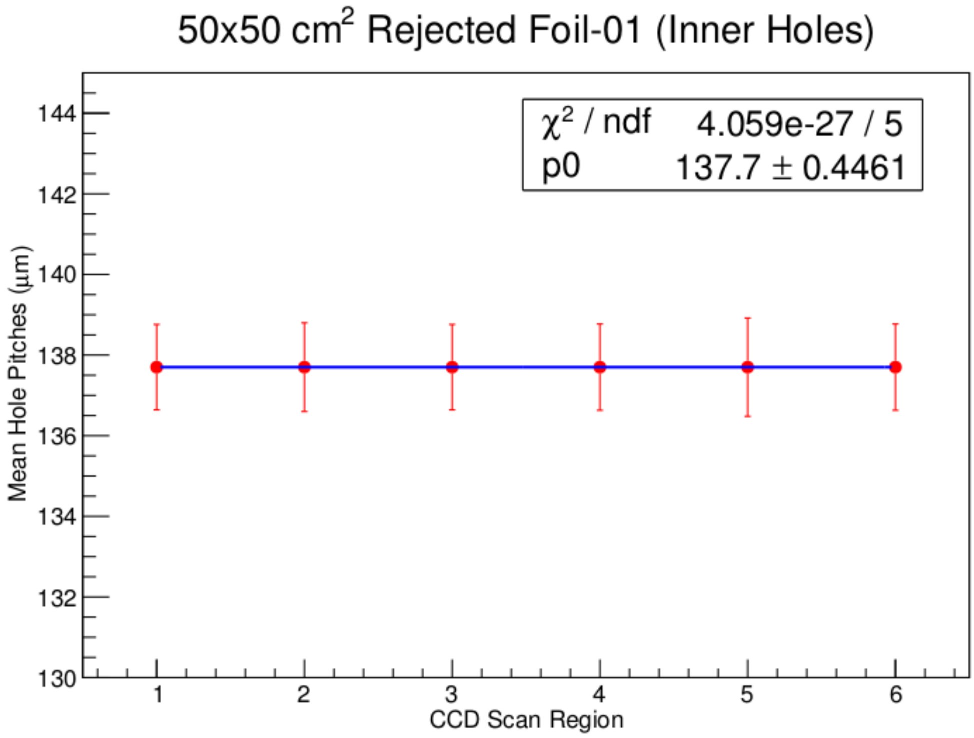

Figure 6: *Pitch as a function of CCD scan region for an initial 50 cm x 50 cm Tech-Etch single-mask GEM foil.*

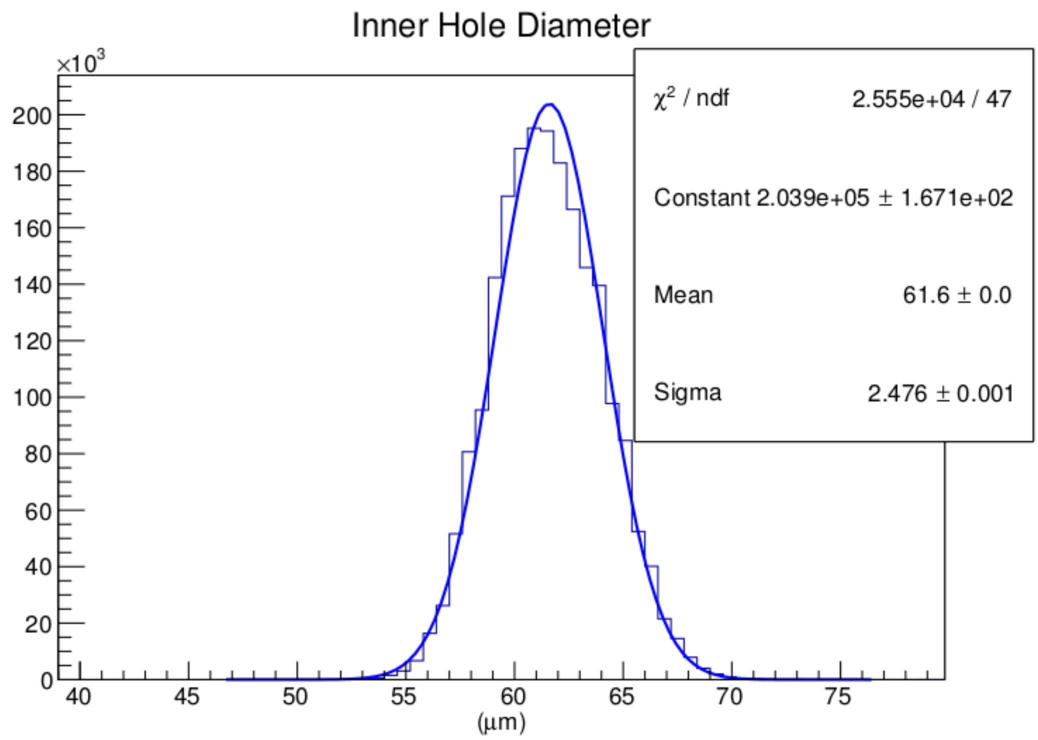

Figure 7: *Inner hole diameter distribution for one of the CCD scan regions of an initial 50 cm x 50 cm Tech-Etch single-mask foil.*

<u>Upgrade of the GEM CCD Scanner</u>

As Tech-Etch continues to work towards producing larger GEM foils, including our EIC common GEM foils design, it is important to have a means in which an exhaustive geometrical characterization of those GEM foils is possible in order to ensure the quality of the foils. However given our current setup, scanning a foil of the size 50 cm x 50 cm is extremely difficult and time consuming. Foils larger than 50 cm x 50 cm simply cannot be analyzed on our current CCD scanner due to their size. In light of this an initiative to upgrade our CCD scanner has begun.

We have begun discussions with Dr. Carl Haber (LBNL), who had suggested that we consider the tubular imaging technique that he currently uses. This technique would allow us to scan large GEM foils at a much faster speed than we currently can. The basic concept behind the tubular imaging method is to wrap the GEM foil around a plexiglass cylinder. The cylinder dimension and radius can be chosen to satisfy the foil dimensions (somewhere around ~60 cm x 150 cm) that are desired. The cylinder can then be rotated via a rotational stage. A CCD camera mounted in front of the cylinder would scan the foil as it rotates. The camera would be attached to a stage, which would allow it to traverse the length of the cylinder. To maintain focus of the images as the scan is performed a laser displacement sensor can be used to keep the camera focused.

Because we will need to backlight the foil in order to be sensitive to the inner hole diameters, our current CCD scanner has the GEM foil sitting on top of a glass plate, which is above an LED light. For the tubular imaging setup we will place lights inside of the plexiglass cylinder in order to backlight the foil. To insure that the CCD images are not distorted in anyway when switching material from glass to plexiglass, an initial test was performed where we replaced the glass stage in our current CCD scanner with plexiglass stages of varying thicknesses (0.25 in – 0.5 in) and scanned previously scanned 10 cm x 10 cm GEM foils. We found no deviation of the geometrical values measured using the plexiglass at any of the thicknesses (0.25 – 0.5 in) from those previously measured, which used a glass stage.

Additionally, we have upgraded our computer hardware. This upgrade desperately needed and included adding CPUs, a new video card, memory, and updated operating system.

Common Large EIC GEM Foil Design

The three institutions, FIT, UVa, and Temple University have been meeting on a biweekly basis to develop a single large EIC GEM foil design that meets the needs of each institution. With this common GEM foil 3 types of prototype EIC triple GEM chambers will be built, with each institution focusing on building the chambers using different assembly techniques. All institutions have now agreed upon a common GEM foil design. This design is discussed in the combined eRD3+eRD6 proposal along with a dedicated funding request to order large GEM foils from Tech-Etch. Tech-Etch has agreed to our request and is committing internal resources to this new development. It goes without saying that the production of large GEM foils is the last step in our R&D program. It would be a huge success for the EIC R&D program if the completion of this development could be accomplished.

DREAM Chip Implementation

A prototype setup for a GEM detector which incorporates the DREAM chip into its readout system is now in preparation at Saclay. One 40cm x 40cm triple-GEM detector has been shipped to Saclay for those tests. The complete setup will be transferred to Temple University once the complete setup has been commissioned at Scaly.

What was not achieved, why not, and what will be done to correct?

Tech-Etch Single-Mask 50 cm x 50 cm GEM Foil

Tech-Etch recently saw it's lead technician heading their GEM foil production leave. They have recently hired a new technician to take over the GEM effort at Tech-Etch, however the training and catching up of the new technician has caused a slight delay in the progress of optimizing the 50 cm x 50 cm foils.

Single-mask 40 cm x 40 cm Triple GEM Detector

All of the equipment needed to build triple GEM chambers has been acquired, with the exception of the frames. This includes the fixtures for electrically testing, stretching and gluing the foils, which is shown in Figure 3. We are now currently waiting on the full completion of the dedicated clean room, which requires the instillation of a dedicated nitrogen gas line.

It is planned to build two FGT-type triple-GEM detectors using Apical spacer grids. The design has already been discussed in the previous reports. We expect to have all Apical rings available shortly with the change of the base material from Kapton. Furthermore, we plan to use only single-mask produced GEM foils, which we have already received and electrically and optically measured.

Single-mask 10 cm x 10 cm Triple GEM Detector

Using the Tech-Etch 10 cm x 10 cm GEM foils, we would like to build a prototype detector with the goal of characterizing the detector gain as well as studying different clustering options.

We have acquired all the tools needed, with the exception of the frames, needed to build the 10 cm x 10 cm chambers. Again we are awaiting the installation of a dedicated nitrogen gas line and are in talks with facilities on getting such a line installed. We have ordered a mini-X-ray tube with a gold target (same tube used by FIT and UVa) and are now looking into placing an order for a ^{55}Fe source. A CAEN HV system has been commissioned and tested via LabView software, which will be used to preform the clustering studies.

DREAM Chip Implementation

The setup of a GEM readout system based on GEM detectors is not completed yet mainly because of the delay in funding this effort. However, we plan to complete this development by the end of 2015.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

Commercialization of Large GEM Foils

The most critical item that needs funding is the continuing development of commercially available large area GEM foils from Tech-Etch. These foils will not only play a vital role in EIC GEM tracking R&D, but the entire nuclear and particle physics community. A detailed proposal for the continuation of large area GEM foils can be found in the combined eRD3+eRD6 proposal.

CCD Scanner Upgrade

As Tech-Etch continues their 50 cm x 50 cm single-mask GEM foil development, and they begin looking into even larger GEM foils, it is crucial to be able to exhaustively check the electrical and geometrical integrity and reproducibility of the GEM foils. For this we would like to propose that we continue upgrading our CCD GEM scanner. We would like to continue pursuing the route of the tubular imaging method. This would include:

- Purchasing the plexiglass tube, rotation stage, camera stage, laser distance sensor, and CCD camera
- Using Matlab to develop software that would be control the devices and process the images in order to obtain the geometrical properties.

Construction of 10 cm x 10 cm Triple GEM Detector

With the Tech-Etch 10 cm x 10 cm foils exhaustively tested for electrical performance and build quality, one of the remaining areas to systematically characterize is the gain performance of the foils. We would like to:

- Purchase frames and a ^{55}Fe source to compliment the mini X-ray tube that we have acquired, as the rates between the two sources are very different.
- Construct a 2D X-ray scanner. This would allow us in an automated way to traverse the active area of the GEM foil with an X-ray source and be able to correlate the gain with different areas of the foil. We also plan on using the 2D scanner with the already developed and commissioned CAEN HV system to study clustering schemes. We already poses the hardware needed for the X-ray scanner and just need to write the automation program.

Construction of 40 cm x 40 cm Triple GEM Detector

With the 40 cm x 40 cm triple GEM detectors we would like to investigate new methods of separating the foils via Apical spacers. Such a method would allow us to further reduce the material budget. Because this test requires the building of triple GEM detectors, we could at the same time use these detectors to characterize the gain on Tech-Etch's 40 cm x 40 cm foils as described in 10 cm x 10 cm triple GEM detector funding request. Because the 40 cm x 40 cm GEM foils are produced with the STAR FGT Gerber file, all of the materials and tooling, except for the frames, are already in hand.

- We would like to purchase frames and several more 40 cm x 40 cm Tech-Etch GEM foils.

- Implement the DREAM chip into the GEM readout system.

DREAM Chip

We would like to implement the DREAM chip into the single mask 40 cm x 40 cm GEM foils, which use Apical spacers between the GEM layers.

What are critical issues?

After accessing our requests, we would like to highlight two crucial requests. The first is the continuation of large GEM development at Tech-Etch. Without funding for this program, Tech-Etch is likely to shift its interest elsewhere and the program may be terminated. With no other source consistently producing GEM foils this would leave CERN as the only GEM distributor (see the combined eRD3 and eRD6 proposal).

The second most critical request is the funding needed to purchase materials to build a tubular CCD scanner. With Tech-Etch already shipping test 50 cm x 50 cm foils, and plans to go even larger (on the order of 1 m long), it is critical that we have a way to test the quality of the GEM foils. If these are to be used by the nuclear-particle physics community, the quality and consistency of the large foils will need to be proven. Currently we have no way to scan these large GEM foils to test their optical quality.

Additional information: None

Barrel MicroMegas R&D program

Saclay

What was planned for this period?

Our effort during the period from January-June 2015 was divided in two main areas. The first was focused on barrel-type Micromegas R&D. It included characterization of previous Z-type (strips along the beams) prototypes, especially, the careful testing of the cylindricity of the detectors. It also consisted in producing and testing C-type barrel prototypes, namely cylindrical tiles with strips perpendicular to the beam directions. We recall that previous Z-type prototypes were produced and tested. However, some problems induced by dust sneaking in the detector were observed on these prototypes and the design for both Z and C-type barrel tiles needed to be modified to correct this. Also, a scheme for fixing these types of issues was investigated. The R&D during the last period included work on how to correct this dust issue. In addition, two C-type prototypes were received and tested at Saclay in the spring. Even though issues with the drift electrode were observed, due to imperfections in the fabrication process at CERN, we were able to fully test the 2^{nd} prototype and obtain a very good overall efficiency of 98%.

The second area concerns the read-out electronics with the DREAM ASIC developed at Saclay. During the period from January-June 2015 most of the efforts were concentrated on high rate operation of the electronics. The firmware of the controller FPGA of the current Front-End Unit (FEU), housing among others 8 DREAMs and a multichannel FADC, was optimized allowing for better use of the on-chip and on-board memory resources. The choice of the sampling and DREAM read-out clock frequencies was enlarged and an under-sampling option was added (retaining every other sample for readout). The operation of the DREAM ASIC was validated at up to 40 MHz sampling and up to 30 MHz readout clock frequencies. Depending on the operating conditions sustained trigger rates of 40-50 kHz and even 100 kHz was achieved. Very recently, hardware design work has started to adapt the FEU/DREAM electronics to an existing GEM detector. An adaptation PCB is under development. Its production is expected during the summer 2015 in order to be ready for the planned tests in September.

Finally, developments of multiplexed readout are an interesting prospect for large detectors. The use of genetic multiplexing allows a large decrease in the channel count. Planar detectors using this technology managed to read 61 strips with 64 DREAM channels (1 ASIC).

What was achieved?

Z-type Barrel tile

Z-type barrels have strips along the beams direction as shown in Figure 8. We also remind the reader that all detectors studied in eRD3 are of the resistive type, which do not spark as the metallic Micromegas did.

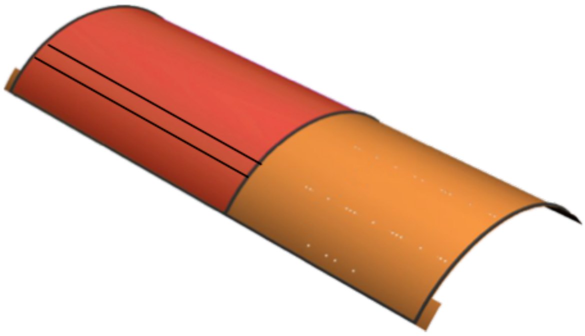

Figure 8: *Z-type barrel tile, the strips are along the beam directions.*

It was important to check that the carbon-composite structure, which makes this detector so lightweight, was strong enough to keep the detector cylindrical. Careful measurements of the cylindricity of the detector were achieved with a Mitutoyo instrument. The different measurement points that were used for this test are shown on the detector in Figure 9. The surveys of the outer and inner sides of the detector are show in Figure 10 and Figure 11. Measurements are indicated as black dots whereas a perfect cylinder is indicated as the red line. Overall the results are very satisfactory. The measured radius was measured to be no more than 2mm off from the theoretical radius for this detector. The drift gap was checked to be uniform along the detector as well.

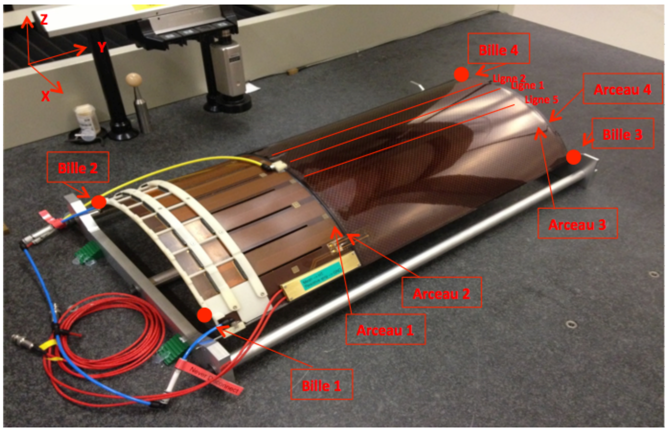

Figure 9: *Z-type barrel tile. In red are represented some of the survey points on the outer side of the tile.*

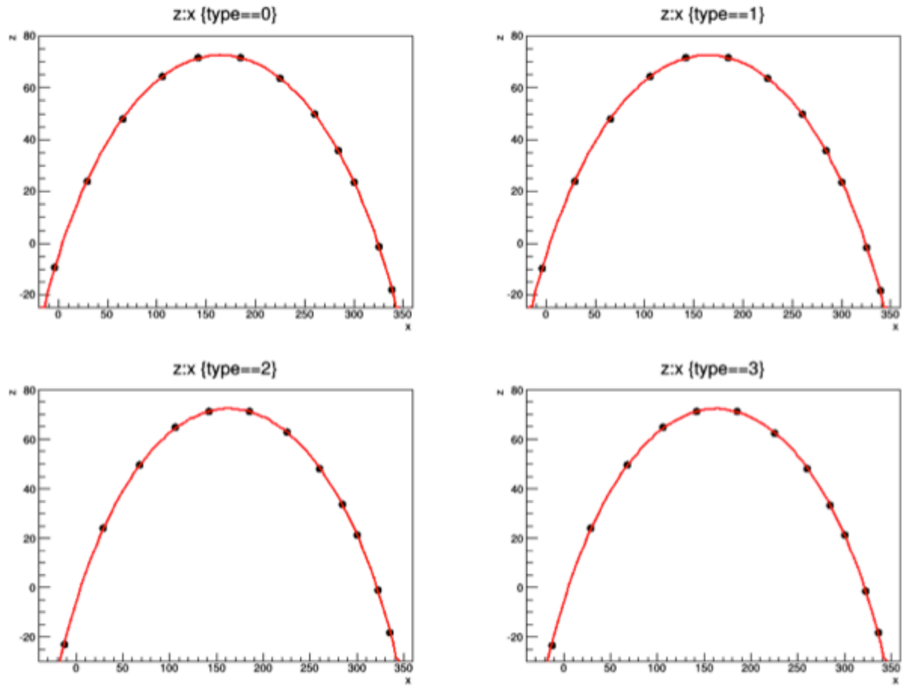

Figure 10: *Measurements of cylindricity of the outer side using the Mitutoyo bench. A circular fit is represented in red.*

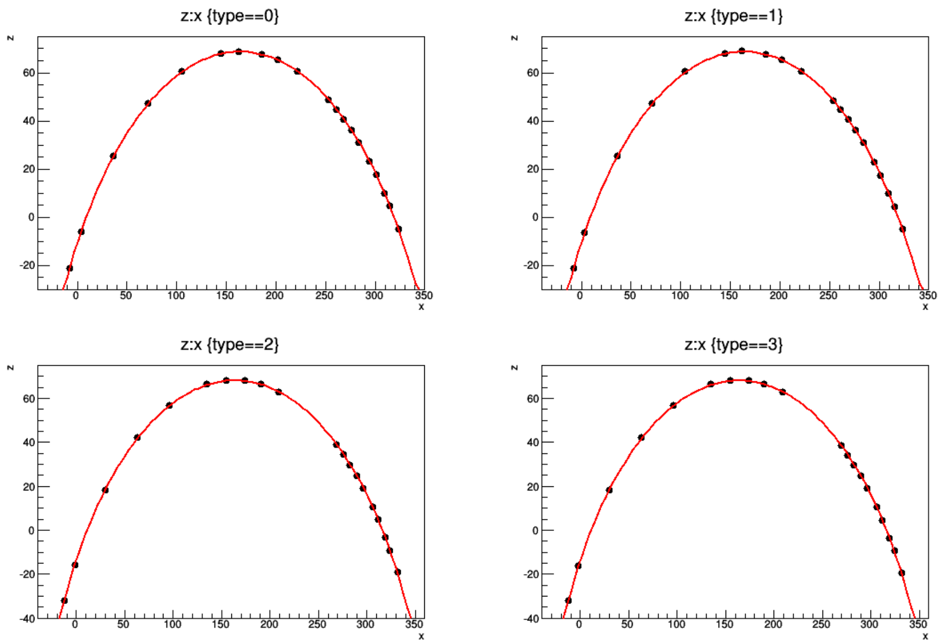

Figure 11: *Measurements of cylindricity of the inner side using the Mitutoyo bench. A circular fit is represented in red.*

After these surveys, the Z-type barrel detectors were tested with an Argon (90%)-Isobutane (10%) gas mixture in a cosmic-ray test bench in order to study its efficiency. The first measurements were very encouraging, but soon, the detector developed a short, which significantly reduced the efficiency in a large part of the detector. This was mostly due to the fact that only a few grounding points were used with this detector, and that all resistive strips were connected together with side-strips, in order to homogenize and minimize the overall resistance. The result of an efficiency run after the short developed is shown in Figure 12.

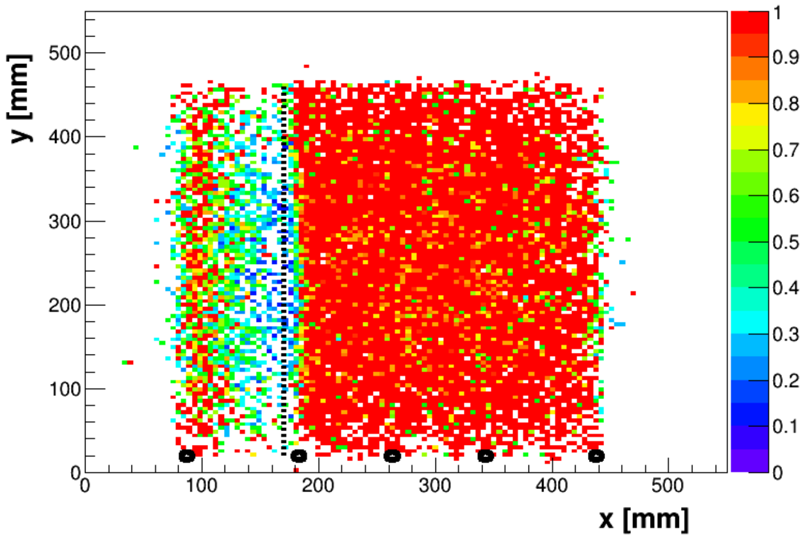

Figure 12: *2D efficiency of a Z-type barrel detector. The short developed somewhere along the strip represented by a dotted line. The grounding points are represented by black dots. The area in between the two grounding points is rendered inefficient by the short.*

After investigating optically and with a thermal camera, it was found that the short was due to some kind of dust in between the micro-mesh and the strips. A fixing scheme was developed, consisting of pouring a plastic compound in the problematic area of the detector in order to completely isolate the area. This scheme was tested on the 2nd Z-type prototype, which developed a similar problem, and the result after fixing is shown in Figure 13. The point where the compound was poured is clearly non-efficient, but the rest of the detector is fully efficient and can be used. The issues with the dust pointed out the need for a class-100 clean room for the integration of these detectors. Since these incidents, the following prototypes never developed this kind of problem. In any case, our fixing scheme works flawlessly if the need arises.

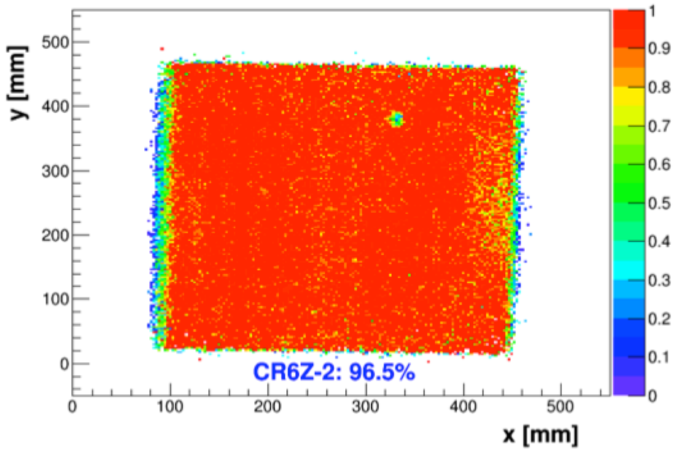

Figure 13: *2D efficiency of a Z-type barrel detector after fixing a shorted area with a plastic compound. The detector despite the repaired area is 96.5% efficient overall.*

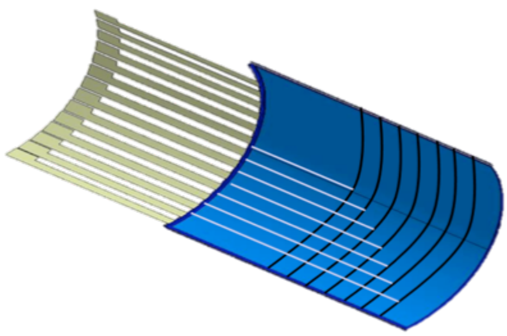

Figure 14: *C-type barrel tile. The strips are circular, perpendicular to the beams direction.*

A spatial resolution of 200µm has been measured with tracks perpendicular to the readout plane. This measurement is at the limit of the performances of the test bench.

In the same conditions, the measured time resolution is around 25ns, which is higher than the 15ns expected from previous detectors. Inhomogeneities in the resistive layer have been observed and an offline software correction is under investigation.

C-type Barrel tile

C-type barrel detectors have circular strips perpendicular to the beams direction as shown in Figure 14. It was the first time that such detectors were produced by CERN. They represent a significant challenge since the signal is transported to the back of the detectors through feed-throughs and return strips, increasing significantly the total capacitance. In addition, these types of detectors tend to have more strips and the density may require several PCB layers on the back-side in order to put all connectors.

The two first prototypes of the C-type detectors arrived at Saclay in the spring, and were prepared and tested shortly after. The finalized detector is shown in Figure 15 along with other Z-type detectors. In addition to the detector PCB, the drift layer is also purchased from CERN. This thin Kapton layer is 150 μm thick and has a thin copper layer on the inside in order to produce the drift field. Unfortunately, there was a mistake during the production process of the drift electrodes at CERN. This had the consequence that the first of the two prototypes was not useable. We are currently in the process of investigating if a repair can occur. The second detector could still be tested and characterized despite a less-than-ideal situation with the drift electrode.

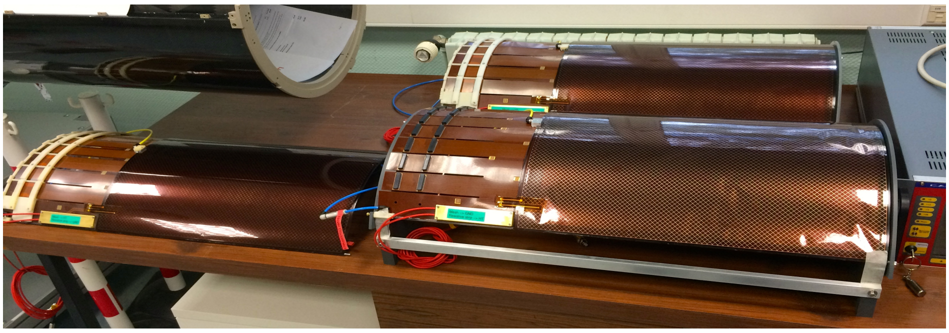

Figure 15: *Left: Z-type barrel detector. Right: C-type barrel detectors. The issue with the drift electrode is clearly visible as "waves" appear on the surface of the Kapton surface depending on the room temperature. This detector was however still useable.*

Similarly to the Z-type detectors, the C-type prototype was fully characterized in a cosmic ray bench. The 2D efficiency is shown in Figure 16 and averages about 98% efficient on the sensitive region of the detector.

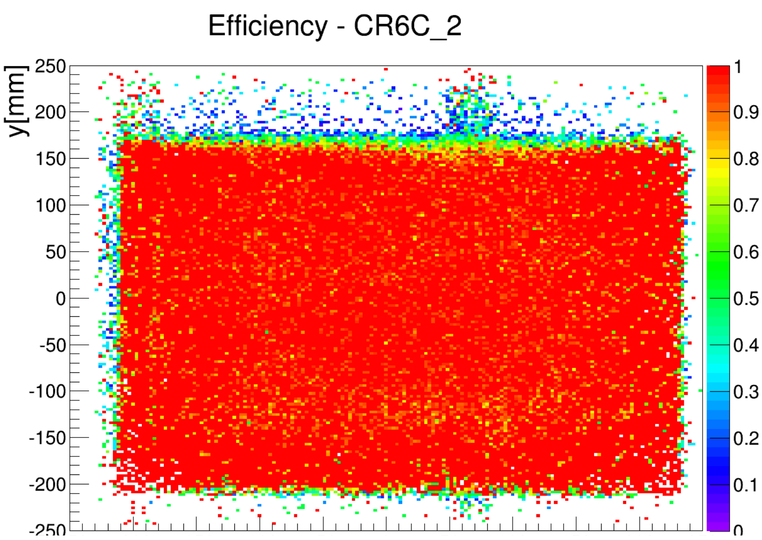

Figure 16: *2D efficiency of a C-type barrel detector. Overall the detector is fully efficient (~98%) in its sensitive zone. The upper non-efficient zone corresponds to the grounding area and is expected.*

The additional length of the return strips used to connect the readout C strips to the side of the detectors brings a slight increase in the electronics noise. However this does not impact the performances of the detectors and similar performances compared to the Z detectors are reached; that is to say 200µm spatial resolution and 25ns time resolution.

DREAM electronics

A test bench, common for several projects (Asacusa, CLAS12, EIC) and dedicated for the read-out electronics tests and validation, has been assembled. Part of it is shown in Figure 17. It accounts for up to 18 FEU cards (~9,200 electronics channels; part of the frontend boards are visible in the upper carte) and includes a backend electronics and a clock / trigger distribution modules (a lower VME crate).

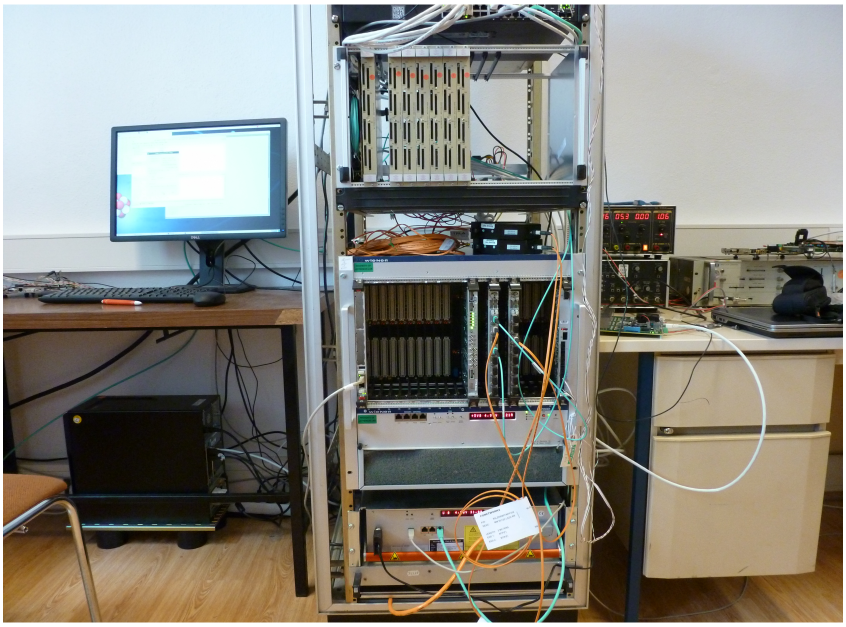

Figure 17: *Electronics test bench.*

In order to asses its high rate operation capability the read-out electronics it was operated in the zero-soupression mode. For each trigger a test pulse was generated on one channel of all 8 DREAMs of a FEU. For a given test run a subset or all available FEUs were participating in data acqusition. For the channels with the charge depositions above the preloaded thresholds a programmable number of samples were retained and read-out for event building and further analysis. Mostly these were the preselected fired channels, with very few additional channels that eventually were selected due to an instanteneous noise. The random trigger source was used throughout the tests. The only constraint imposed on the trigger generator was the inter trigger delay that had not to be less than the sampling period times the number of samples to read-out (e.g. for sampling period of 36 ns and 8 read-out samples the minimal allowed inter trigger delay was 8*36 = 288 ns). Bursts in the trigger signals were absorbed by various memory buffers available in the DREAM ASICs, frontend units and the concentration electronics. The busy signal was imposed on the trigger generator when the number of events treated in the system was exeeding a programmable threshold, typically ~50 events. The overall dead time of the read-out system was continuosely monitored.

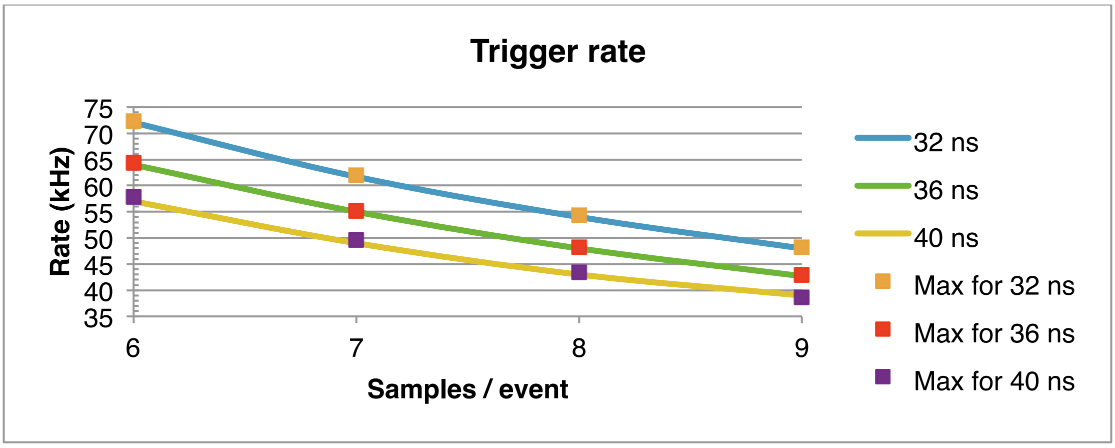

Figure 18: *Trigger rate as a function of the number of samples per event.*

Figure 18 shows the measured sustained trigger rate (solid lines) and calculated maximum possible trigger rate (square points) as a function of the DREAM read-out clock period and a number of read-out samples. The absolute maximum for the trigger rate is determined by the DREAM read-out clock and the number of retained samples per trigger. Indeed, whether the electronics operates in the zero-suppression mode or in the full read-out mode, all 64 channels must be read from the DREAMs for each sample. This operation takes 72 clock cycles (*i.e.* 2.592 µs for the 36 ns clock period). For each trigger it is repeated as many times as the number of requested samples, thus setting the minimum time to service the trigger (in the case of the 36 ns clock example and for 8 samples the minimum time to service triggers is 8*2.592 = 20.736µs corresponding to a maximum trigger rate of ~48 kHz). The results presented in Figure 18 show that the system operates at the maximum trigger rate imposed by the read-out capabilities of the DREAM ASICs. The observed dead-time for all these measurements was ~3%. If the trigger generator rate was further increased, the system continued to operate stably, though obviously it was introducing higher dead-time by asserting the busy signal.

Additional measurements showed that retaining less number of samples allowed near 100 kHz operation (3 or 4 sample per trigger). However, it has to be mentioned that the DREAM analog memory is shared between the trigger pipeline and the read-out buffering needs. Increasing the trigger latency requires more of the DREAM memory to be reserved for the pipeline purposes, leaving less space for read-out buffering. To prevent DREAM memory overflow the system asserts the busy signal earlier increasing its contribution to the overall dead-time. Many entries (operational conditions) in the pre-calculated use case tables were verified by measurements and were found to be consistent with the expectations.

The patented multiplexed Micromegas detectors, or "MultiGen", allow the use of large active surface read out by a very limited number of electronics channels. The MultiGen detectors have an active area of 50 x 50 cm^2 and provide the 2D position of a particle using only two connectors of 61 channels each. The multiplexed detectors use the fact that the Micromegas signal touches more than one readout strip at the same time in average (with a cluster size of ~2.5 for a pitch of 488µm). The MultiGEN readout scheme puts a couple of strips next to each other at only one place in the detector, therefore any signal touching more than one strip is reconstructed at a unique location. This technology cannot be used with high particle rate however it has a great potential in low rate application such as muon tomography.

What was not achieved, why not, and what will be done to correct?

Large 2D curved and resistive prototype could not be produced. Indeed the individual Z and C-type arrived late from CERN with issues that needed R&D time to solve. We will continue working on producing a large 2D curved resistive detector during next funding cycle.

The activities related to the development of the DREAM-based VFE module were delayed due to putting the priority on the improvement of high rate operation. Furthermore, the plans were rectified to first develop adaptation PCBs to perform read-out tests of a GEM-type detector with the existing electronics. The VFE developments are planned to start during the summer and will last until the end of 2015. The tests with the VFE electronics are scheduled during the first trimester of 2016.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

- Micromegas detector: 2D curved resistive prototype: this technology has the clear advantage of minimizing the amount of material with respect to two 1D detectors.
- Electronics: Design and fabrication of a Very-Front-End-Board (VFEB) with only 1 DREAM ASIC which will allow to have the control and digital treatment away from the detector, hence limiting the impact in terms of material budget while keeping the high performance of analog sampling.

Additional information: None

Manpower

One postdoc was supported at 100% level on this effort along with two graduate students providing assistance with the move to our new laboratory and setting up all necessary equipment for a period of three months.

External Funding

Both groups, Temple University and Saclay did not receive any other funding in support of the program discussed here.

Publications and Conferences

Please provide a list of publications coming out of the R&D effort.

- Temple University has hosted in May of 2015 an EIC tracking R&D workshop (https://phys.cst.temple.edu/~surrow/EIC-RD-WORKSHOP/index.html) which was dedicated to tracking detector development for an EIC.
- An abstract has been sent to the 2015 IEEE conference requesting to present results of the on going commercialization of large GEM foils produced by Tech-Etch. Additionally FIT, UVa, and Temple University have sent in an abstract, which highlights the work done by the three institutions towards a and common EIC GEM foil design.
- Recently, a paper documenting the results of the Tech-Etch produced 10 cm x 10 cm and 40 cm x 40 cm single-mask GEM foils has been submitted to Nuclear Instrumentations and Methods Section A. The submitted paper can currently be found on the arXiv:1506.03652

Budget request

The main items for the budget request for FY16 are as follows:

- 1 postdoctoral research associate (continuing)
- Domestic travel (BNL / UVA / FIT / JLab / IEEE Conference): $7.5k
- International travel (Saclay): $6k
- Material: $15k for Frames, HV Foils, 2D readout foil (40cm x 40cm), small frames and scanner setup
- Large GEM foil order: $33k for large GEM foil order
- Services: $30k for DREAM chip development and MicroMegas prototype at Saclay

The full budget breakdown is shown in Figure 19.

DOE EIC R&D / eRD3 - Dr. Bernd Surrow	
	FY 2016
PERSONNEL	
Post Docs	$44,556
Undergraduate support	$0
Total Salaries	$44,556
Fringe Benefits	
29.9% on Post Doc	$13,322
Total Fringe	$13,322
Total Personnel (A7+A8)	$57,878
Travel - Domestic	$7,500
Travel - International	$6,000
Material	$15,000
Equipment	$33,000
OTHER:	
Services	$30,000
Total Direct Costs	$149,378
Modified Total Direct Costs (MTDC)	$116,378
F&A: 26% Y1 / 26% YR 2	$30,258
Total Project Costs	$179,637

Figure 19: *FY16 budget breakdown for eRD3 EIC R&D program.*

References

[1] A. Accardi *et al.*, Report on ‘Electron Ion Collider: The Next QCD Frontier-Understanding the glue that binds us all’, arXiv 1212.1701 (2012).

[2] M. Villa *et al.*, Nucl. Instrum. Meth **A 628**, 182 (2001), 1007.1131.

[3] M. Posik and B. Surrow, ‘Research and Development of Commercially Manufactured Large GEM Foils’, arXiv: 1506.03652 (submitted to NIM A).